UNDERSTANDING ENTRAINMENT AT COASTAL POWER PLANTS: INFORMING A PROGRAM TO STUDY IMPACTS AND THEIR REDUCTION

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Cover photo: Aerial view of Moss Landing Power Plant (at center).
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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

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- Renewable Energy Technologies
- Transportation

Understanding Entrainment at Coastal Power Plants: Informing a Program to Study Impacts and Their Reduction is a staff report for the Environmental Effects of Cooling Water Intake Structures project (contract number 500-04-025) conducted by the Moss Landing Marine Laboratories. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-5164.

Table of Contents

List of Figures

List of Tables

Abstract

A significant portion of California's generation capacity, approximately 45 percent, is represented by facilities located along the state's coast and estuaries that use once-through cooling technology, where the ocean water is passed by the condenser and then discharged back into a water body. This cooling technology withdraws approximately 17 billion gallons of seawater per day when all plants using this technology are fully operational. Although some of these facilities have been operating since the 1950s, a scientific understanding of the ecological effects of the use of once-through cooling is quite limited. The California Energy Commission is funding research to understand and provide tools to minimize the effects of once-through cooling on California's coastal resources. In this study, the authors reviewed existing literature on the effects of once-through cooling, identified areas where knowledge gaps exist, and convened an advisory group to address those gaps. The areas of concern that were identified are the ability to: measure effects, determine the affected area and related oceanography, identify entrained species, determine useful technology to implement for reducing entrainment, and determine when mitigation is useful or successful. This information will be used to help identify once-through cooling research that should be funded in the future.

Keywords: Once-through cooling, marine, coastal, estuary, entrainment, impingement, intake screen, entrainment research, power plant

Executive Summary

Introduction

Approximately 45 percent of the California electricity generation facilities located along the state's coast and estuaries use once-through cooling technology. Collectively, the permits for these facilities allow them to draw approximately 17 billion gallons of seawater per day to cool the condensers (although they draw less water when they are not operating at full capacity). Water is brought into the plant, passed by the condenser once, and is discharged. The effects from cooling water withdrawals are characterized as *entrainment* (where small aquatic organisms are carried by the cooling water into the power plant and assumed killed by heat, turbulence, and/or chemicals) and as *impingement* (where the cooling water intake traps larger organisms against the intake screens). Thermal effects occur when discharged cooling water is hotter than the temperatures of the receiving water body. Withdrawal of cooling water from California's waters potentially harms millions of aquatic organisms each year, including fish, fish larvae and eggs, crustaceans, shellfish, sea turtles, and marine mammals. The largest impacts are likely to come from the removal of early life stages of fish and shellfish. Although many of the facilities have been operating since the 1950s, there are still knowledge gaps about how to accurately quantify and reduce the impacts to the ecosystem.

In 2004 the United States Environmental Protection Agency (U.S. EPA) announced a new rule (Phase II) under the Clean Water Act Section 316(b) requiring the reduction of entrainment and impingement effects from cooling water intakes. As part of the process of quantifying those impacts and implementing measures for their reduction, operators were developing sampling plans and monitoring. Such information was required before issuance of National Pollutant Discharge Elimination System (NPDES) permits. Most of the 2004 rule was remanded in federal court in early 2007. The U.S. EPA officially suspended the rule and issued a memo stating that "best professional judgment" will be the standard until they notice and develop a new rule. The California Energy Commission (Energy Commission) requires a license before construction or operation of a new power plant over 50 megawatts (MW) and when an operator upgrades or repowers a facility over 50 MW. The Energy Commission can require monitoring and mitigation as part of its licensing process. The State Water Resources Control Board is also in the process of developing a rule to implement in California, because it is responsible for implementing the 316(b) regulations in the state. (Section 316(b) of the Clean Water Act requires facilities to use the best technology available to minimize the entrainment and impingement of aquatic organisms in cooling water intakes.)

For rules such as those outlined above to be effective, the findings resulting from monitoring and other actions must be placed within a context that can be used by regulators. This context can come only from a larger biological and ecological understanding of the ecosystems in which the plants operate.

Purpose

This project summarized the existing research on the effects of once-through cooling and identified knowledge gaps to help inform research to be funded. The knowledge gaps discussed in this report are not meant to be all-encompassing, but rather, focus on some areas that have the greatest uncertainty and that were discussed at the initial Water Intake Structure meeting on April 13, 2005, which was held at the Moss Landing Marine Laboratory.

Recommendations

Understanding model performance is crucial if users are to place confidence in their predictions of entrainment losses. Several models are used to determine affected species population level effects from entrainment. No investigations of model sensitivity have been conducted, whereby differing starting values such as mean, median, or mode are input and the effect on parameter estimation is quantified. Variation in the output parameters, as determined by inputting a range of values such as a maximum and minimum, is rarely employed (but highly recommended) for assessing confidence levels in loss estimates. Further, the performance of available models has not been assessed to determine biases and other limitations of their application; such assessments are recommended.

Accurate life history data are essential for accurately determining an effect from entrainment. The estimation of life history parameters is paramount to understanding the effects of entrainment on ecosystems because all of the models used to estimate them use these data as a starting point. To understand how the removal of individuals affects populations and communities, it is necessary to know age of maturity, longevity, and fecundity of those individuals, which is inferred from good information about the species. Accurate life history information is essential for obtaining robust and reliable estimates of entrainment effects on populations.

Baseline datasets need to be established to identify natural population trends for important entrained species. Baseline datasets can provide information about how entrained and non-entrained populations are faring over time and could be used to place 316(b) studies in the context of what is happening to populations as the result of climate change, oceanic conditions, or other factors, in the absence of entrainment effects. These would be especially useful if they were extended over longer periods. These studies would then be informative for placing the 316(b) studies in the context of longer-term oceanographic trends that affect marine populations. There would be a greater certainty regarding how species fluctuate according to natural cycles, and the magnitude of entrainment losses could be evaluated with regard to these cycles. This would also help determine how best and how often to conduct entrainment sampling to capture ecological variation inherent within the system. One could infer what sorts of oceanographic climates would lead to poor recruitment years and identify periods when potentially important species would be more strongly affected by entrainment losses.

Indicator species should be identified to serve as proxies for those species where information is still lacking. It is unlikely that researchers will be able to obtain complete life history information for all entrained species anytime soon, so indicator species could provide vital information for estimating impacts on those less well-studied species. Indicator species must be good biological and behavioral proxies for those species that are not modeled directly from the perspective of entrainment effects. Research should identify how to accurately and completely sample these species. Because traditional methods for identifying and quantifying indicator species are not always effective or possible under certain conditions or for certain species, the development of alternative methods, such as genetic identification of species, are encouraged. Species with special status (that is, threatened or endangered) whose populations should be monitored closely should be included in these studies.

Improved hydrodynamic modeling is needed to understand the affected areas. Computational fluid dynamics shows great promise in inferring flow patterns resulting from cooling water intake structures and predicting entrainment risk. Computational fluid dynamics is really the only reasonable tool for predicting the impact of future cooling water intake structures or of relocating cooling water intake structures. Such data must be used along with knowledge of the duration of the pelagic (open-ocean) larval life-history phase so that it is known how long species are vulnerable to entrainment, and if other behaviors, such as feeding or reproducing, continue to make species vulnerable at other times.

Implementing technology and determining mitigation effectiveness. Existing technology for preventing entrainment needs to be evaluated in the field under conditions relevant to California power plants and potentially applied along with other, less expensive approaches. There is no one technology that will meet the needs of every power plant. However, fine mesh barriers seem to hold the most promise for use at coastal plants. At this time they all require full-scale field evaluation. The potential for biofouling avoidance and treatment will need to be addressed as part of this testing. Since it is critical to keep fishes off the physical barriers, it is prudent to further investigate the use of multiple simultaneous technologies (that is, screens plus behavioral measures), and it is suggested that such an approach may reduce entrainment far more effectively than any one treatment alone.

Benefits to California

By protecting and conserving the state’s natural resources, all Californians stand to benefit. The populations potentially affected by once-through cooling not only serve important roles in providing food and other direct benefits to humans, but also maintain opportunities for Californians in the areas of tourism and recreation, ecosystem health, and many other benefits that cannot be assigned a dollar value (California Ocean Protection Council, 2006). It is essential to gain an understanding of the effects of once-through cooling on the marine environment to ensure ocean health for years to come.

1.0 Background

1.1. State and Federal Regulations

Thermal power plants larger than 50 megawatts (MW) are required to obtain a California Energy Commission (Energy Commission) license to construct and operate. Although many of the facilities using once-through cooling were constructed prior to the Energy Commission's existence, they are required to receive a permit for activities, including repowering or retrofitting, if those activities include increasing their generation capacity 50 MW or greater. As part of that process applicants may be required to conduct studies on entrainment and impingement and mitigate those effects.

In 2004 the United States Environmental Protection Agency (U.S. EPA) promulgated a new rule (Phase II) under the Clean Water Act Section 316(b) to reduce entrainment and impingement effects from cooling water intakes at existing large electric generating plants. As part of the process of quantifying those impacts and implementing measures to reduce them, operators were developing sampling plans and monitoring as part of the data collection. That information was needed prior to issuance of National Pollutant Discharge Elimination System (NPDES) permits. Under the rule, applicants were required to develop a Proposal for Information Collection (PIC). Clean Water Act Section 401 allows for states to implement the NPDES program and in California the Regional Water Quality Control Boards (RWQCB) issue the NPDES permits. An NPDES permit is required for a power plant to use once-through cooling (OTC) technology. Power plants are required to renew their NPDES permit every five years. The U.S. EPA was sued on the new 316(b) rule by a group of litigants collectively known as Riverkeeper, Inc. and in January 2007 the court issued its decision (*Riverkeeper, Inc. v. EPA.* 2007) remanding sections of the rule back to the U.S. EPA to address including restoration as mitigation, best available technology, costs, and site-specific analysis. Recently, the U.S. EPA determined that the interim standard for compliance with 316(b) will be Best Professional Judgment (BPJ) until a new rule can be promulgated.

There are two other Clean Water Act 316(b) phases (I and III) for which the U.S. EPA recently developed rules. Phase I applies to new electric generating plants and manufacturers that withdraw more than two million gallons per day (MGD) from U.S. waters, if they use 25% or more of their intake water for cooling. Phase III addresses other existing facilities, as well as new offshore and coastal oil and gas extraction facilities that are designed to withdraw at least two million gallons per day.

The State Water Resources Control Board (SWRCB), the oversight agency of the RWQCB, is also in the process of establishing a statewide rule to implement the federal regulations and provide guidance for the types of studies that will be required of applicants for NPDES permits in California. The draft rule was released for public comment in the fall of 2006. The SWRCB will also be required to adopt an environmental document for California Environmental Quality Act (CEQA) compliance.

The California State Lands Commission and the Ocean Protection Council have also issued resolutions in regard to once-through cooling. Although the resolutions are nonbinding, they do identify OTC as an issue that needs to be addressed and recommend that the agencies seek to work collaboratively to reduce the impacts of once-through cooling.

1.2. Once-through Cooling Use in California

Twenty-one power plants in California use OTC technology, meaning that water is drawn into the plant and then discharged. Once-through cooling is different from wet cooling (where water is drawn in and recirculated past the condenser several times and cooled with cooling towers), or dry cooling (where air is used to transfer heat directly to the atmosphere). Once-through cooling technology passes water by the condenser one time before discharging it and uses the most water relative to all other types of cooling systems in California. Once-through cooling is used largely in older plants, circa 1950–1970, that are being retrofitted or repowered (using the old cooling water intake structure, CWIS) for use in meeting California's growing energy demands (such as the San Onofre Nuclear Plant in Figure 1). See Table 1 for a list of power plants in California that use OTC. These plants collectively have a generating capacity of nearly 24,000 MW, and are permitted to draw nearly 17 billion gallons of water per day from coastal and estuarine waters (Foster 2005). Several of these plants have recently been retired or have announced intentions of retiring.

Table 1. California power plants using once-through cooling

Power Plant	***Generation Capacity (MW)***	***Max. Permitted Intake Volumes (MGD)***
1. Alamitos	2083	1275
2. Contra Costa	680	341
3. Diablo Canyon (nuclear)	2200	2540
4. El Segundo	1020	605
5. Encina	965	857
6. Haynes	1570	1271
7. Humboldt Bay	135	78
8. Hunters Point	215	412
9. Huntington Beach	880	507
10. Long Beach	577	261
11. Los Angeles Harbor	472	110
12. Mandalay	577	255
13. Morro Bay	1002	668
14. Moss Landing	2538	1224
15. Ormond Beach	1500	688
16. Pittsburg	2029	1070
17. Potrero	362	226
18. Redondo Beach	1310	881
19. San Onofre (nuclear)	2254	2580
20. Scattergood	818	495
21. South Bay	723	601
TOTAL	23,910	16,925

There are three predominant environmental impacts that occur using OTC; entrainment, impingement, and thermal effects. *Entrainment* is the capture of small, frequently larval, organisms in the water drawn in for cooling coastal power plants. These small aquatic organisms are carried along with the water into the plant where they are presumed (but see Mayhew 2000) killed by thermal, chemical, or physical effects (EA Engineering 2000; Environmental Protection Agency 2004). *Impingement* occurs when the cooling water intake traps larger organisms against the intake screens. *Thermal effects* are caused by cooling water when discharged at a temperature significantly above that of the receiving water body. All of these may affect individuals, populations, and communities.

Although entrainment, impingement, and thermal effects can all be environmental issues, this report focuses on entrainment, for several reasons. More is understood about how to quantify and mitigate impingement and thermal effects. Impingement typically involves larger organisms that are easier to quantify because researchers can sample them directly on the screens, as opposed to indirectly estimating entrainment losses. Thermal effects are problematic primarily for those organisms that are sessile (i.e., not mobile). Again, these effects are sampled relatively easily because they can be directly assessed. Moreover, effects tend to be limited to relatively small geographic areas when compared with entrainment effects. Alternatively, the least amount of information is known about how to characterize entrainment impacts.

Figure 1. Aerial view of the San Onofre Nuclear Generating Station (SONGS)

Photo credit: Southern California Edison

As part of the scoping for this document, Moss Landing Marine Labs hosted a Public Interest Energy Research (PIER)-funded workshop that brought together industry representatives, state and federal agencies, environmental groups, scientific and economic consultants, and academic scientists (Appendices A and B). This report builds upon the knowledge gaps identified in the workshop, although it is not meant to be all-encompassing. Instead, it focuses on the gaps that are best explored by the PIER research program.

2.0 Existing Methods to Determine Entrainment Effects

Why is entrainment a problem? It is generally agreed that the water taken into power plants contains a wide array of organisms that is representative of local ecological communities (York and Foster 2005). The affected communities may be both estuarine and coastal (oceanic), depending upon where the intake pipe is located. Entrained organisms are often small and pelagic; they cannot avoid the intake currents. These include algal propagules, invertebrate larvae, and some fish larvae. These are small enough to fit through any larger mesh screens, so they circulate through the power plant cooling system. Large organisms are usually more mobile and can escape or resist the intake current (Bainbridge 1964; Castro-Santos 2005; Cech et al. 1998; Fletcher 1994), and benthic organisms are semi-protected because of the nature of their attachment (if attached) or their habit of being in or near the sediment.

The ecological community affected will depend upon where the intake is located, how much water is taken in by the plant, its velocity, and at what time of day or season intake occurs. Entrainment was identified as the issue of foremost concern for a majority of this study because it likely causes the largest loss of life and is potentially the most complicated in terms of determining ecological impacts.

Once an organism is entrained, it is expected that it will not survive (Environmental Protection Agency 2004). Although this assumption has been challenged, and some procedures have been proposed for estimating actual deaths due to entrainment (see for example ASA Analysis and Communication 2005), it is still the standard policy to assume that what enters the plant does not come out alive. The challenge, therefore, is to quantify what is entering the plant and reduce it if necessary. Careful and well-designed studies are required to determine what is potentially or very likely entrained. Once the larval loss is determined (see Figure 2), then the impact of these losses on the remaining populations and communities must be determined through modeling.

Although these procedures have been adopted, and power plant operators have developed studies to meet their regulatory requirements, there are knowledge gaps, including the following:

- Appropriate sample design and techniques.
- The basic life history data required for modeling effects for many entrained organisms.
- Model accuracy.
- Effectiveness of technology to reduce entrainment.
- The potential for habitat compensation.
- Assessment of cumulative impacts.

The authors seek to address the most pressing knowledge gaps and those that can help inform the regulatory process.

Unfortunately, unlike impingement, where losses are determined by simply counting the species trapped on the intake screens, it is not possible to capture every organism that enters the plant (that is, without completely inhibiting water flow). Collecting organisms from inside the intake pipes can be misleading because the fouling community that settles on the inside of the pipes consumes a large fraction of the organisms entering the power plant (J. Steinbeck, Tenera Environmental, pers. comm.). Collecting organisms only from immediately in front of the intake pipes is also of limited use because accurate and regionally applicable life history information is not available for all entrained species. Without this information, the demography of the populations is not known, the fraction of the population that is being lost to entrainment cannot be inferred, and the effects of that loss cannot be determined. Therefore, studies of the source water body and the community it contains must be carefully designed to capture and quantify the diversity of organisms *potentially* entrained. This information forms the basis for understanding the impact of losing those organisms that presumably *are* entrained, those sampled immediately in front of the intake.

Reviews of existing entrainment studies are generally in agreement that earlier studies were poorly designed and often incomplete (Foster 2005), though this is in part an artifact of the era in which the studies were conducted. In most cases, the sampling method was inappropriate, and sampling effort was not designed such that the study might be able to detect entrainment impacts, if they existed. The U.S. EPA (2004) found the same result when reviewing studies conducted in the 1970s and 1980s at sites throughout the United States. Both reviews note that the entrainment studies generally lacked the rigor to conclude with any certainty that ”no adverse impacts“ were occurring.

2.1. Entrainment Sampling Methodology

Figure 2. Night sampling for larvae using a bongo net. In this image the net has been retrieved after being towed and is being rinsed to ensure all contents are moved down towards the cod end for sorting and analysis.

Image provided by Eric Miller of MBC Applied Environmental Sciences

Only seven of the 21 OTC plants in California have conducted studies of entrainment effects that meet current scientific standards. All were conducted after 2000, including Encina, Huntington Beach, Morro Bay, Moss Landing, Potrero, San Onofre Nuclear Generating Station (SONGS), and South Bay. Six of these studies were listed in Foster (2005), although the studies at SONGS and Potrero were incomplete with regard to entrainment impacts. Since the publication of Foster

(2005), Encina has conducted impact analyses (the data of which is unavailable at this time), and SONGS and Potrero have completed ongoing analyses. The remaining studies were deemed inadequate in Foster's (2005) review with regard to estimation of entrainment impacts. Therefore, seven studies of California power plants could be used to determine losses attributable to entrainment. See Table 2 for entrainment sampling information.

Having limited studies is problematic because the Clean Water Act's Section 316(b) Phase II rule, which came into effect in July 2004, attempts to establish performance standards for OTC plants that will reduce entrainment by 60% to 90% (U.S. EPA, undated). Since the rule was suspended following the recent court ruling (Riverkeeper, Inc. v. EPA II 2007), U.S. EPA has instated Best Professional Judgment. Because impacts and mitigation will be determined on a case-by-case basis, it is important to have the best information available, and although the regulatory process has changed the potential ecological impacts remain.

York and Foster (2005) provide an overview of how current studies are conducted in their Appendix C, which we summarize in the following text. Technical working groups formed to guide study development, implementation, and analysis provide(d) oversight for many of the recent studies in California and are helping to reverse the lack of scientific rigor apparent in the earlier studies. Most studies start with a literature review in conjunction with preliminary sampling or pilot studies. The goal of this combined approach is to determine (1) which larval species are in the water and likely to be entrained (or are entrained), and (2) the source water body from which they originate. Sampling then occurs for a set time period and with a certain methodology.

Sampling is usually conducted with a 300-micron mesh plankton net, thereby targeting larvae of that size or larger. Sampling occurs at the intake and at locations away from the intake for at least one year. The frequency of sampling and the sampling depth will depend upon variability in larval behavior and abundance. The number and spatial arrangement of locations away from the intake will also depend upon this information, taken together with information regarding the area of water that is affected by the intake (see Chapter 2). Therefore, to allocate samples in space and time, researchers consider the particular characteristics at the power plant's specific location.

York and Foster (2005) recommend a technique of sampling that is meant to describe, as accurately as possible, the species composition, number, and size of larvae in the water that might possibly be entrained (away from the intake) versus those that will absolutely be entrained (immediately in front of the intake), so that a reasonable estimate of the community and its losses due to entrainment can be determined. This estimate of the community is roughly equivalent to the source population (Steinbeck et al., in review), which is the density or abundance of species in the source water—the area from which an organism might be entrained.

Table 2. Potential entrainment impacts at California power plants for which data have been collected. Updated from York and Foster (2005). * = fished species.

Power Plant	***Intake Environment***	***Density (#/1000 m³) and Richness (# taxa) of Entrained Larvae***	***Most Abundant Entrained Species***	***Mitigation for Entrainment Impacts[+]***
Diablo Canyon[A] (nuclear)	Central Coast; shore in open coast rocky cove	Fish density: 465 richness: 218 Crabs density: 10,960 richness: 9 Urchins density: 593 richness: 2	*Rockfishes, Clinid Kelpfishes, Blackeye Goby, Monkeyface Eel, Smoothead Sculpin, Snubnose Sculpin, *White Croaker, *Cancer Crabs, *Yellow Rock Crab, Purple Sea Urchin	120–240 hectares (296–593 acres) of rock reef
Huntington Beach[B]	South Coast - South Palos Verdes Region; subtidal open coast sand bottom	Fish density: 407 richness: 53 Crabs density: 667 richness: 8	Gobies, *Anchovies *Spotfin Croaker, *White Croaker, *Queenfish, *"Croakers," Blennies, *Mole Crabs, *Cancer Crabs	TBD
Morro Bay[C]	Central Coast; shore in estuary/harbor	Fish density: 590 richness: 92 Crabs density: 24 richness: 8 Clams & Mussels density: 1.8×10^6 richness: > 5	Gobies, Staghorn Sculpin, Blennies, Shadow Gobies, Jacksmelt, Blackeye Goby, Northern Lampfish, *Cancer Crabs, *Clams, *Mussels	93–307 hectares (230–759 acres) estuarine habitat
Moss Landing[D]	Central Coast; shore in estuary/harbor	Fish density: 638 richness: 67 Crabs density: 3.9 richness: 8	Gobies, Bay Goby, Blackeye Goby, Pacific Staghorn Sculpin, Blennies, *White Croaker, *Pacific Herring	460 hectares (1135 acres) of estuarine wetlands
Potrero[E]	South San Francisco Bay; shore in estuary	Fish density: 953 richness: 77 Crabs density: < 1 richness: 7	Gobies, Yellowfin Goby, Bay Goby, *Pacific Herring, *Northern Anchovy, *Cancer Crabs, European Green Crab	393–939 hectares of estuarine habitat

Table 2. (continued)

Power Plant	Intake Environment	Density (#/1000 m3) and Richness (# taxa) of Entrained Larvae	Most Abundant Entrained Species	Mitigation for Entrainment Impacts+
19. San Onofre[F] (nuclear)	South Coast; subtidal open coast sand bottom	Fish density:1590	*Northern Anchovy, *White Croaker, *Queenfish, Gobies, Blennies, *Grunions & Smelts	60.7 hectares (150 acres) of estuarine wetlands, plus kelp forest
21. South Bay[G]	South Coast-Southern San Diego Bay; shore in estuary	Fish density: 2744 richness: 44	Gobies, *Bay Anchovies, Blennies, Mudsuckers, Pipefish, Yellowfin Gobies	406 hectares (1003 acres) of estuarine habitat

+. Based upon Habitat Production Foregone (HPF), the area of habitat needed to replace larvae killed by entrainment. These areas vary in part because of the use of different Proportional Mortality (PM) values (e.g., PM average versus PM max.). The most appropriate value to use needs to be better resolved (York and Foster 2005).

A. Entrainment data from Tenera (2000a) and mitigation from CCRWQCB (2005) using average PM max.
B. Generation capacity, intake vol., and entrainment data from MBC and Tenera (2005) and preliminary mitigation estimate from using range of average PM max. to average PM max. 95% confidence interval (CI) (Raimondi pers. comm.).
C. Generation capacity, intake volume, and fish and crab entrainment data from Tenera (2001), clam densities from Geller (pers. comm.),and mitigation from CCRWQCB (2004) using average PM and average PM max.
D. Entrainment data from Tenera (2000b). Mitigation from Anderson and Foster (2000) using average PM.
E. Entrainment data from Tenera (2005a). Mitigation calculated from data in Tenera (2005a) from Foster (pers. comm.).
F. Entrainment data from P. Raimondi, (pers. comm.), mitigation data from California Coastal Commission (1997).
G. Entrainment data from Duke (2004), mitigation calculated from data in Duke (2004) using average PM max= 0.134 and area of source water habitat = 3033 hectares.

Conversion factors: 1 cubic meter (m^3) = 264.173 U.S. gallons; 1 liter = 0.001 m^3; 1 hectare = 1 x 10^4 m^2 = 2.471 acres; 1 acre-foot = 325,851 U.S. gallons; 1 megawatt = 10^6 watts.

Although the recent studies are more scientifically defensible, there are ways to strengthen the standard study design even more. Steinbeck et al. (in review) compare and contrast the differing methods applied most recently for assessing larval fish entrainment effects at three California power plants: the South Bay, Morro Bay, and Diablo Canyon nuclear power plants. They suggest that the most important factors for these assessments are sampling frequency, type of collecting gear, and the mesh sizes used with that gear (all of these can introduce bias into the results). They recommend that these factors be customized to the types and biological activities of the organisms inhabiting the study area such that the organisms are sampled effectively and completely. These modifications to a standardized sampling program should be based upon information gathered in pilot studies and from the available literature for the region. The available literature, however, is often scant, and this represents a knowledge gap. How such modifications might manifest is elaborated upon in the following paragraphs.

Sampling frequency is quite simply how often samples are taken in the area. Some of the questions that must be addressed include: When is the best time of day to sample and how often should sampling occur? Answering these questions entails decision making over several temporal scales, ranging from the scale of day versus night to weeks versus months. How you sample must be determined based upon the biology of the species in the area. Some larvae are active (and therefore vulnerable to entrainment) at night, while for others, this is true during the day. A sampling program must capture this variability to assess impacts to these species.

Further, sampling must capture not only the species that are long-term residents of the affected region, but also seasonal migrants. Even if the larvae are present in the region for a short time, if they are mostly entrained at that time, there is the potential for strong population and ecosystem-level effects. This is particularly important for species that breed seasonally and for short periods of time. For example, some larvae may be abundant in conjunction with short-lived oceanic events, such as bursts of upwelling. These may last only a few weeks or days. But, these windows of time may be strongly correlated with timing of reproduction for that species and may represent most of the species' reproductive activity for the year. If the larvae of this species are entrained in large numbers during these small windows of time, then entrainment may actually take a much larger, and very significant, fraction of the population than might be apparent from sampling evenly over the year at monthly intervals. Sampling at high-frequency intervals may be cost-prohibitive over the course of a year or more, but intensive sampling usually can occur during the appropriate oceanic events or seasons, as determined by the biology of the species in question.

Because cost is an issue, additional questions remain, including: Is it better to sample less often but for a longer time period? And, how do you maximize the information collected and minimize the costs associated with sampling? Because sampling requires considerable staff resources and tends to be very expensive, most sampling programs last for one year only (or perhaps 18 months) and are not repeated until relicensing is needed. There is still debate among biologists and regulators over whether this time frame is sufficient for capturing the information necessary to determine entrainment impacts for species and communities. Local species populations will fluctuate with larval fish recruitment success. Varying oceanic conditions (currents, temperature) may cause population fluctuations over time scales longer than one year.

Although Steinbeck et al. (in review) generally feel one-year studies are sufficient, ultimately the answers to the questions above will, once again, depend upon the biology of the species in question. If the region is consistently inhabited only by year-round residents that consistently and reliably reproduce at known times of the year, a much-streamlined sampling regime could be designed to effectively capture these species. However, the implementation of such streamlined studies is hampered by a lack of biological information necessary to be assured that such an approach is reasonable. If long-term studies are cost-prohibitive when conducted as part of 316(b) requirements, long-term studies at other locations would be useful for inferring the time scale over which populations naturally fluctuate, and for establishing a baseline against which populations affected by entrainment could be compared.

Similarly, gear and mesh sizes should be tailored to target species identified through pilot studies or in studies of nearby regions (Steinbeck et al., in review). York and Foster 2005 noted that sampling is most often conducted using a 300-micron plankton net. In the studies reviewed by Steinbeck et al. (in review) a combination of gear types was employed to effectively capture and quantify species at risk of entrainment. Different types of sampling gear and mesh sizes will target different sizes and types of larvae. This is not only because the larvae vary in size, but also because different species have different habits and behaviors, including differing abilities to detect and escape collection gear. The tendency of any one gear type to "select for" species with certain behaviors or ability is known as *gear bias.* The use of multiple types of gear can help to balance out specific biases, and exactly which gear types work best will depend upon the target species.

In general, Steinbeck et al. (in review) note that a "prescriptive approach," whereby one sampling design is created and applied to all CWIS impact studies, is not possible because potentially affected species will vary from site to site. Therefore the sampling design required to capture the variables that describe those species will potentially need to vary as well. The knowledge gaps that the research program can help fill include:

- How long should the study last (e.g., one year, two years, or more)?
- When and how frequently should samples be taken (e.g., day vs. night, seasonally)?
- Does the sampling gear capture everything being entrained (e.g., are mesh sizes correct)?

In many cases literature regarding species' behavior and life history characteristics is needed to determine the best sampling strategy, and this literature is lacking for a number of potentially affected species.

2.2. Sample Identification Methodology

Because available methods and costs are limiting, typically only large larvae (such as fishes or crabs, see figures 3 and 4) are identified and counted. There are other segments of the ecological community which are not identified and sampled. Smaller larvae (other invertebrates) typically cannot be identified with existing methods, even though their populations are likely effected. Planktonic invertebrates and phytoplankton are typically not sampled because of their excessively small sizes and the commonly held assumption that their rapid growth and fast population turnover suggest that ecological impacts are unlikely, although this has not been studied. Adult stages are not sampled for entrainment impacts because adults are highly unlikely to be entrained, because they are too large to fit through the intake screens.

Figure 3. Northern Anchovy, Engraulis mordax, adults. Larval anchovy are frequently documented in entrainment studies.
Image courtesy of the National Undersea Research Program

Once sample units are appropriately allocated and samples properly gathered, the next step is to determine which species to enumerate and how.

Figure 4. Enigmatic cancer crab megalopa, a larval life history stage. Megalopa are one of the larger and more readily identified invertebrates in larval samples.

Image courtesy of University of Washington

If unlimited resources were available, identifying and quantifying every species in the sample would be the surest way to gain accurate information. Indeed, this is the staff recommendation of the SWRCB and RWQCB (D. Gregorio, pers. comm.). In reality, this is unlikely to occur because of difficultly in accurately identifying many larvae—especially invertebrate species and eggs that are too small, too fragile, or too difficult to distinguish from one another.

Even for those species that can be identified down to species level, such as many fish larvae, limitations of time and personnel often require that samples be sub-sampled in a systematic manner. Steinbeck et al. (in review) summarize several approaches and make recommendations for sub-sampling and processing based upon the species that are being quantified. This is probably adequate for those species that can be enumerated visually (~0.3 millimeters, mm). However, still ignored is that fraction of the sample that cannot be enumerated, which includes most invertebrate larvae and nearly all fish eggs. Promising new approaches that go beyond physical enumeration include sampling intake water for genetic markers. This approach has proven effective for invertebrate species with very small larvae such as clams and mussels (Jonathan Geller, Moss Landing Marine Laboratories, pers. comm.); species typically not enumerated due to the difficulty and expense associated with identification. Abundance estimates for these two organisms ranged upward of one million per 1000 square meters (m^2) in entrained water at Diablo Canyon nuclear power plant (Jonathan Geller, Moss Landing Marine Laboratories, pers. comm.). If these were competent larvae that would have settled if not entrained, this removal could result in significant losses for the local population. This approach may work equally well for other species that are not identifiable following the sampling effort.

2.3. Long-term Datasets

Long-term datasets may be a powerful way to accurately determine entrainment losses and to place them within a context of natural or non-power-plant related population changes. They provide a way of measuring population level changes over periods greater than one year (the typical length of a study associated with 316[b]). While many 316(b) studies are conducted for one year, and the number of larvae potentially entrained in that year are estimated, it is very difficult to determine if that year of study represents an "average" year. If the study was conducted during a year in which certain species were very abundant, the loss of those species due to entrainment may be overestimated when the results are extrapolated beyond that particular year and used to infer "typical" losses. In the same manner, one-year studies may completely miss species that are in other years significantly affected by entrainment. Long-term datasets can help to determination how long 316(b) studies should last and how often they should be repeated. Long-term datasets may also be important for designing monitoring programs.

As eluded to earlier in this report, long-term data provide a mechanism for quantifying how populations and communities fluctuate in response to perturbations other than entrainment, many of which may be natural perturbations. Even if these datasets are compiled in areas without power plants, they can provide a baseline measure of population fluctuations against which potential losses from entrainment can be compared. This sort of comparison is essential for determining if the losses from entrainment are truly significant for the population, both locally and at larger scales, and for determining if fluctuations detected in populations are attributable to entrainment at all.

Similarly, long-term datasets could also be used to infer when power plant losses would be more or less detrimental to the population. For example, temperatures affect food availability, which affects the condition of the females, and in turn the energy invested in offspring and/or egg production. Females may spawn for shorter intervals, or even not at all, during years in which the temperature deviates significantly from normal. During these years a typical fractional loss due to entrainment, even if small, would be far more devastating than in other years. Further, one could infer what sorts of oceanographic climates would lead to poor recruitment years and identify in advance periods when potentially important species would be more strongly affected by entrainment losses.

Unfortunately, there are few long-term datasets that are compatible in terms of their location and sampling strategy. To date, the research team identified a small suite of studies being conducted in the very nearshore regions of central California that have the potential to be used in conjunction with entrainment studies (Table 3). At present, these studies may need to be extended in terms of their sample location to incorporate sites and species nearer to power plants, such as Morro Bay or Diablo Canyon. Depending upon the exact study locations and their proximity to power plants, they may be useful as indicators of baselines for populations that potentially experience entrainment effects, or they may have the ability to directly detect entrainment effects. This effort will require collaboration between the researchers listed and the Energy Commission. A thorough survey of Southern California research programs revealed that no studies have been conducted in the last thirty years to estimate abundances of potentially entrained species (i.e., larvae of any species in the water column), except for the ichthyoplankton surveys that the Vantuna Research Group has been conducting in King Harbor monthly since 1974. Programs like California Cooperative Fisheries Investigations (CalCOFI) collect larvae but no longer sample nearshore with their current regime. If there is the potential to establish such nearshore datasets, given the density of power plants in this region of California, it would be informative for placing the 316(b) studies in the context of longer-term oceanographic trends that affect marine populations.

Table 3. Surveys of the California near- and far-shore habitats

Survey Name	Species and Life Stage	Location	Survey Time Period	Methods
PISCO	Recruitment age fishes	Much of coastal CA, concentrated Santa Barbara and Monterey Bay areas	Since 1997	Placing settlement plates and collection traps placed intertidally and subtidally
NOAA Fisheries, Santa Cruz Lab	Flatfish and rockfish recruits	Monterey Bay north to Pt. Arena (diver counts limited to much smaller area)	Ongoing for 20+ years for diver surveys, much more recent for trawls and traps	Diver counts (rockfish only) via SCUBA, traps, and trawls
Vantuna Research Group	Conspicuous juvenile and adult fishes	King Harbor, Redondo Beach, Rocky Point, Palos Verdes	Quarterly, 1974 to present	Transects via SCUBA
Vantuna Research Group	Conspicuous juvenile and adult fishes	Catalina, Santa Barbara, San Nicolas, San Clemente, and Coronados Islands	Quarterly, 2000 to present	Transects via SCUBA
CSU Northridge/ Vantuna Research Group	Juvenile and adult fishes	San Diego Bay	Three seasons 1999–2002, 2005, continuing on 3–5 year schedule	Net tows
CSU Northridge/ Vantuna Research Group	Juvenile and adult fishes	Newport Beach – Santa Barbara and Catalina Island	Quarterly, 1995 to present	Gill net
MBC in conjunction with select power plant operators	Demersal fishes and invertebrates	Ventura to Huntington Beach	Approx. semiannually	Net tows
California Polytechnic State University/ Vantuna Research Group	Juvenile and adult fishes	Morro Bay	Seasonally, 2006–2008	Net tows

2.4. Life History Data

Determining entrainment impacts depends upon an understanding of how and when species might be affected. Knowledge of larval duration for all species in question, for example, is required as length of the pelagic larval life history stage varies among aquatic species. This is directly proportional to the length of time that a species is at risk of entrainment. Similarly, species characteristics including spatial and temporal distributions (daily, seasonal, or annual movements), habitat preferences (e.g., depth and substrate), swimming ability, sensory ability (to detect and avoid intake), size and age, feeding and reproductive habits, and physiological tolerances all influence the likelihood of being entrained (Environmental Protection Agency

2004). When this information is taken together, the period of vulnerability to entrainment is varied for any given species, and is at present not well known.

Determination of life history parameters can be viewed as basic research. However, this document provides examples of where such information is needed, so that it can be applied in the context of understanding the ecological impacts of entrainment on species and populations. For example, life history data inform the sampling protocols discussed earlier. Sampling must be designed to capture the organisms in the area, and organisms are in an area as the result of their life history. Life history data are needed to apply many of the population models used for determining impacts to a species or population (see Section 2.5). Life history data are also needed for determining the affected area (see Section 4.0). The basic biology of the organism is encompassed within the term "life history," and this biology is the essential ingredient for determining entrainment impacts. The ongoing need for this basic information regarding species at risk of entrainment should not be underestimated.

2.5. Application of Models for Estimating Impacts

Once species are identified and enumerated, the population and community-level effects caused by the removal of these species needs to be determined (Van Winkle and Kadvany 2003). Because the long-term data against which to compare species abundances and infer such effects is not typically available, models are used to estimate the potential effects of the removal of these organisms. The models recommended for use by the RWQCB for California OTC plants are Adult Equivalent Loss (AEL), Fecundity Hindcasting (FH), Empirical Transport Model (ETM), Proportional Mortality (PM), and Habitat Production Forgone (HPF), and all of the models are used to calculate something slightly different. These models fall into two basic categories, depending upon the input data that they require: those that require life history data and those that do not (York and Foster 2005). The choice of which model to apply has been hotly debated. In practice, model choice is often made based upon ease of calculation, which is determined by the amount and type of information at hand. In addition, there are other models used for assessing entrainment that are not identified above, and that may be useful in assessing entrainment effects in California.

Two models that require life history data are AEL and FH. These two models require, as a first step, species-specific estimates of larval mortality due to entrainment. Modelers estimate this by multiplying larval abundances per volume sampled in front of the intake by the volume of water taken in by the plant over a year. Modelers can use this mortality estimate in conjunction with larval sizes (a proxy for age) and knowledge of natural mortality rates to estimate the number of future adults lost, or AEL (but see also Jensen et al. 1988; Rago 1984). Similarly, FH is used to back-calculate the number of adult females whose reproductive output was lost to entrainment. This number can be used to forecast future adult females lost (assuming a 50:50 sex ratio, or any other known sex ratio; see Strange et al. 2004).

Such models require good life history information—which is lacking, especially for California coastal species—as input parameters. This lack of data was made abundantly clear by a recent EPRI report (LWB Environmental Services, Inc. 2005), where life history parameters were determined for 16 marine and 10 freshwater species that were frequently entrained according to the EPRI database. Of these species, only one was from California (partly because most of the utilities that belong to EPRI are not in California). That this information is completely lacking for California's affected species was echoed by Steinbeck et al. (in review). Estimating life history parameters—which include age of maturity, longevity, and fecundity—is paramount to the application of AEL and FH models and understanding the impact of the removal of individuals on populations and communities. More complete demographic information for potentially affected species is also identified here as an area of need.

In the absence of any suitable life history information, studies utilize models like the ETM (Boreman et al. 1981). The ETM relies on a fairly crude estimate of water taken into the plant; volume per unit time. Historically, this model incorporated fisheries management techniques for assessing stock size for a given species. Entrainment losses were considered in a manner analogous to the population losses related to commercial fishing, and a Ricker-style stock-recruitment curve was employed to infer population sizes and impacts.[1]

In California and elsewhere, this stock-recruitment step has been replaced with PM. Proportional Mortality is simply the number of larvae that are actually entrained (those at the intake) relative to those that could be entrained (those in the source water; see Chapter 3). Proportional Mortality often incorporates all captured larvae and is presented as an average PM across all species captured; modeling is not performed on a species-specific basis. Because of this inclusiveness, PM is preferred by some over models such as AEL or FH that typically consider only the loss of "economically important" species such as those that are commercially fished. The PM model is the most commonly employed single metric for quantifying larval entrainment (Strange et al. 2004).

However, PM is often used in California in conjunction with HPF (also known as Area of Production Forgone, or APF) in a two-step approach to estimating the impacts of entrainment losses and possible mitigation for those losses. The HPF model uses PM in conjunction with some knowledge of the area of the water that contained the lost larvae such as ETM. These two factors are taken together to estimate the area of 100% larval loss, which is the HPF. This model does not represent actual habitat loss, but instead represents the amount of habitat that would need to be created or replaced to produce an equivalent amount of larvae to that lost to entrainment. Depending on the inputs to the HPF model, the area of habitat that normally results in a restoration requirement can vary. Also knowing whether the habitat identified through HPF model results (amount and quality) truly compensates for the impacts has not been researched. For more discussion of this topic see the habitat compensation and restoration section (Section 5.0) below.

[1] A Ricker-style, stock-recruitment curve contrasts the number of larvae with the number of spawning adults; where this relationship peaks is considered the sustainable yield or the number of adults that can be taken without affecting the population.

Steinbeck et al. (in review) promote the use of ETM modeling because demographic models, at present, have varying, or even unknown, levels of confidence. The ETM model can be used to estimate losses due to entrainment given a certain cooling water withdrawal rate when virtually no other life history parameters are known. However, it is not clear how any of the models perform relative to one another. If the data existed such that any model could be equally applied as easily as another, which model would be the best option? This question cannot yet be answered, and the biases associated with each model (and how those biases affect model performance) are not fully understood. Understanding model biases and performance remains an area needing research attention.

All modeling efforts, be they entrainment or any other sort, come with trade-offs such as ease of use and broad applicability at the cost of specific and precise information. Models such as ETM could be far more precise if volume per unit time were scaled according to the size and shape of the area of influence, especially if the dynamic aspect of the area of influence could be incorporated (see Chapter 3). Strange et al. (2004) also note that the best applications of ETM also require knowledge of life history parameters to fine-tune the result. Further, the more information that can be entered into a model, the more precisely entrainment impacts can be understood. For example, the models are typically used to estimate impacts only for certain species of interest; not all species that are entrained. The species normally modeled are commercially or recreationally fished species, or species that are the most common in the sample. It is not known if, or how well, the model outputs describe affects on the species that are not being measured, or those species that interact with modeled species but are not affected directly. At present, it is necessary to determine how well the model outputs represent the entire potential impact, for both modeled and unmodeled species. Thus, manipulating these models and understanding their performance limits represents a research need.

Environmental groups in particular are concerned over the failure of models to recognize non-consumptive values, or those values of organisms other than as food for humans, as well as other potential economic benefits of consumptive uses, such as processing cast-offs used in livestock food and fertilizers (C. Shuman, Staff Scientist, Heal the Bay, pers. comm.). Similarly, concern has been voiced over the failure of the models to incorporate secondary impacts (D. Nelson, Coastal Alliance on Plant Expansion, pers. comm.), such as impacts on species that feed on entrained species. These criticisms directly relate to how the models are applied and the values assigned to the predicted losses. Similarly, the criticism that models only consider the loss of economically important species is really not a criticism of the models so much as of the modeler and how the models are applied. Unfortunately, as noted above for model selection, the species that are selected for modeling are often chosen based upon available information and the ability to apply the models. As there is not a great deal of life history and/or behavioral information available, the models are applied to the best extent possible.

Because there is a lack of good information for every captured species, one might use "indicator" species (ASA Analysis and Communication 2002a; EA Engineering 1999). The indicator species concept is only as good as the species chosen to play this role. Since indicator species are meant to represent uncounted species, they must have similar biological attributes. Indicator species should have similar life history parameters (age of maturity, longevity, fecundity), trophic roles (piscivore, planktivore), and community functions (nocturnal versus diurnal; benthic versus pelagic) so that the impact of their removal on the remaining population and community are estimated by the proxy species as closely as is possible.

This leads to the question of whether or not species of special concern should be enumerated. The problem with species of special concern is that they may be rare, difficult to find within the sample, and not representative of other species. However, such species are often species of concern because of these very factors; quite often species of special concern are threatened or endangered species or populations. Therefore, if the goal is to fully understand the ecological impact of entrainment, species of special concern have to be enumerated (ASA Analysis and Communication 2002b).

Indeed, one of the requirements for an indicator species to work is that the species that are not directly modeled be properly represented by those that are. This, too, requires some baseline level of reliable and accurate life history information. A key finding of this report is that effort needs to be devoted to determining these life-history parameters for potentially affected species. To date sufficient information is not available to satisfactorily determine which are the best indicator species.

Which sorts of values to input into any given model is also worth consideration. If, for example, one were estimating PM, one could use the mean abundance of larvae very near the intake and estimate an average overall loss. Alternatively, one could use the maximum abundance of larvae very near the intake during the study period to get a conservative estimate of mortality or the minimum to get a very optimistic estimate of mortality due to entrainment. Another way the models have been used is to include estimates of variation (see also Steinbeck et al., in review), whereby ranges of values are used as input. This provides for the estimation of effects with statistical confidence limits and provides a measure of the degree of certainty to place in the results. Along the same lines, there has been no investigation of model sensitivity, whereby differing starting values (i.e., mean, median, mode) are input and the effect on parameter estimation is quantified. Because the information available for any given species will vary tremendously (and therefore the models that can be used will vary similarly), understanding how the models collectively respond given different inputs is identified here as an area of need.

2.6. Cumulative Impacts

The term *cumulative impacts* refers to those impacts that result from many detrimental factors acting on a population simultaneously. This could be one OTC plant plus commercial fishing, pollution, and habitat degradation, or many OTC plants operating in the same area and drawing from the same source water body. The reason for concern regarding cumulative impacts is that most entrainment studies take into account only the impact potentially caused by the plant itself. But, this impact is not placed within the context of other ongoing impacts that may or may not make the population more vulnerable to losses, or more likely to be seriously harmed by losses. Cumulative impacts remain virtually unknown and completely unstudied in the context of any California OTC plants, and this remains an area of research need.

3.0 Determining Affected Area and Source Water Area

There are two areas of water that need to be considered to understand the magnitude of entrainment effects: the source water and the area of influence. The *source water* is the volume of water from which entrained organisms originate (P. Raimondi, pers. comm.). For example, if a larval fish hatched in waters near San Francisco and then was entrained in the Diablo Canyon Nuclear Power plant (in San Luis Obispo County; Figure 5), the source water for the plant would extend to at least San Francisco. The source water is always much larger than the area of influence. The U.S. EPA defines the *area of influence* as that portion of the source water body that is hydraulically influenced by the intake of cooling water. Determination of area of influence is required by new 316(b) rules for most California plants.

Figure 5. Diablo Canyon Nuclear Power Plant and its oceanic intake

Photo courtesy of Wikimedia Commons

Steinbeck et al. (in review) suggest that a complete hydrodynamic understanding of the entire source water area is essential for reliable entrainment loss estimates. In fact, it is this hydrodynamic understanding that is used to determine the source water area. The origin of entrained larvae is inferred based upon residence times in the water and coastal current patterns. Residence time is estimated using information regarding larval developmental rates and sampling regimes focused upon determining said residence times. Such knowledge could be improved with the addition of studies that conclusively determine larval origin, such as otolith microchemistry. The added influence of current patterns may be complicated, depending upon the system considered. In estuaries and enclosed bays, for example, there are multiple influences on water movement, but still these are constrained by the boundaries of the enclosure. On the other hand, open coastal waters have few static boundaries and are therefore much more complicated. The size and extent of the source water can have a huge affect on the model outputs.

Coastal intake patterns are often influenced by multiple, dynamic factors. These include the source water body type (bay versus open coast), water temperatures, direction and rates of ambient flows, and tides and seasonal circulation patterns, as well as larger, more constant oceanic circulation patterns. Geological features such as bottom topography will also affect flow patterns. At the smaller scale, additional factors are important, such as depth of the intake; distance from shore; the proximity of intake withdrawal to the discharge; the size and shape of the intake structure; the intake velocity; the timing, duration, and frequency of intake; and the percentage of source water that is used in OTC (Environmental Protection Agency 2004).

One method of determining flow patterns is by direct field sampling using flow meters. Flow meters are usually placed within the source water body at positions near and away from the water intake. Many such measurements can be used to construct a flow map, and it is from this map that the area of influence and potentially the source water body is inferred. This analysis requires knowledge of the flow regime present in the area in the absence of the intake so that the influence of the CWIS is not over- or underestimated. The process may need to be repeated several times to account for temporally varying processes acting on the source water body.

Flow markers, such as dye, are indirect measures of flow and are used to actually visualize the flow. The movement of the dye is used to infer the position of streamlines in relatively simple, unidirectional systems. *Streamlines* are lines of flow along which the velocity is constant. Linear flow does not cross streamlines. Thus, by applying dye at points farther and farther from the intake, one can delineate streamlines that are influenced by flow into the CWIS (Alden Research Laboratory 2004) and those that are characteristic of the undisturbed source water body. In more dynamic systems, streamlines may not be present and instead plumes of water would be marked and their boundary determined. The advantage of this approach is that it takes into account the many and varied processes acting on the source water body and thus, they do not need to be measured separately (Alden Research Laboratory 2004). The potential disadvantage is that the sampling regime for placing flow meters or markers must still take into account these features so that their effects are incorporated into the net result. The more complicated the flow within the source water body, the more difficult it is to accurately visualize.

Computational fluid dynamics (CFD) is a computer model or simulation of flow patterns into the CWIS that can serve as a possible alternative to direct field sampling. Computational fluid dynamics also requires explicit knowledge of such features as bottom topography. However, if reliable input data can be obtained, multiple models incorporating any number of conditions can be generated relatively quickly and easily. A recent EPRI study attempted to apply several of the software packages that are readily available to six different case studies that offered different source water bodies. Though applying computer models to determine the area of influence was not difficult, Alden Research Laboratory (2004) found that the model was more time consuming with more dynamic source water bodies. The EPRI report concludes that CFD provides an accurate indication of the location and magnitude of the CWIS area of influence (Alden Research Laboratory 2004).

Unfortunately there are no studies performed or mentioned by Alden Research Laboratory (2004) that compare flow patterns inferred by CFD with flow patters measured by direct field sampling. This is currently an area of research need, particularly for hydrodynamically complex coastal waters where most OTC plants are located. The potential for CFD to provide useful information regarding the area of influence and source water body is quite good. The primary caveat with the use of CFD is that the resulting flow patterns are *theoretical*. Like any modeling effort, the output is only as good as the input. Therefore, there is a need to determine exactly which sorts and amounts of data are required to produce precise outputs. Further, CFD is the only option for modeling the effect of *new* CWIS or of *relocating existing* CWIS, because the effects of a CWIS that does not exist cannot be measured directly. Therefore, research efforts should also determine the accuracy of CFD modeling in terms of its application to CWIS and refine the models as necessary.

4.0 Reducing Entrainment through Technology

There are several ways of implementing technology to reduce entrainment, including the following:

- Moving the intake.
- Installing variable speed pumps.
- Installing barriers or screens in front of the intake.
- Installing fish bypass systems (for impingement).

Devices that rely on physical exclusion of entrainable organisms include traveling screens, wedgewire screens, and aquatic filter barriers. Devices that provide structural guidance to fishes include louvers and angled screens (usually with a fish return or bypass system). Finally, behavioral barriers include velocity caps, sound generating devices, lights, bubble curtains, and others. Table 4 summarizes the general application of these technologies to OTC plants in California and elsewhere.

Table 4. Entrainment reduction technologies employed in California OTC facilities and elsewhere (updated from York and Foster [2005])

Technology	*In Use in CA OTC plants*[2]	*In Use Elsewhere*[3]	*Considered Experimental*	*Potential Capitol Costs Associated with Implementation*[4]	*Potential Operation and Maintenance Costs*[4]
*Fish Return	X	X		Not known	
*Behavioral Barrier	X	X	X	$2,633,000	$180,00
*Traveling Screen	X	X		In place in nearly all CA plants	$251,000
*Coarse Mesh Ristroph Screen	X	X		$6,830,000	$546,000
Fine Mesh Ristroph Screen[1]		X	X	$10,867,000	$609,000
Narrow Slot Wedge-wire Screen[1]			X	$25,240,000	$640,000
*Wide Slot Wedge-wire Screen		X	X	$2,595,000	$163,000
Aquatic Filter Barrier[1]			X	$30,974,000	$2,263,000
*Velocity Cap	X	X		In place in all open-coast CA plants	$42,000
Variable Speed Drive	X	X		Not known	

* = likely to have far greater benefits for reducing impingement; entrainment benefits may be small unless entrainable organisms are specifically considered in the design.

1. Identified as having the potential to meet the entrainment reduction performance standard by U.S. EPA's Phase II Ruling.
2. From York and Foster (2005), Tim Havey (pers. comm.).
3. From U.S. EPA (2004).
4. Annualized average cost ranges in 2002 dollars based upon historical data. From Taft and Cook (2005).

The U.S. EPA publication *Technical Development Document for Final Regulations Addressing Cooling Water Intake Structures for New Facilities* (U.S. EPA 2001) summarizes technologies used at particular sites and their effectiveness at reducing impingement and entrainment (Tables 5-1 and 5-2 on pages 5-18 and 5-19). For a synopsis of expected construction and operation and maintenance (O&M) costs, albeit not necessarily for plants in California, see Tables 2-5 on pages 17–19 of the U.S. EPA Proceedings Report for their 2003 report, *Symposium on Cooling Water Intake Technologies to Protect Aquatic Organisms* (U.S. EPA 2005). For a review of the California studies completed to assess the economic costs associated with the ecological impacts of once-through cooling, see York and Foster (2005), Appendix E. Taft and Cook (2005) provide a general estimate of the costs of implementing the below-mentioned technologies in terms of start-up plus operation and maintenance.

4.1. Moving the Intake

The general idea behind relocating a cooling water intake is to move it from an area of high biological activity to one of lower productivity and lower densities of entrainable organisms. For example, since estuaries are often areas of high biological productivity, it may be beneficial to relocate estuarine intakes to deep (out of the euphotic zone), offshore areas with lower concentrations of eggs and larvae. Another advantage is that the deep oceanic water is colder, so a lower volume of water can be used to achieve the same degree of cooling. If some species spawn in deep water or if tidal currents distribute larvae evenly throughout all depths, moving the intake could have no effect on reducing entrainment losses. In that case it may be possible to use multiple pumps, each at a different depth, and only use one or two at a time to avoid withdrawing water from a depth known to be occupied by certain fish species. This strategy requires a knowledge of local fish assemblages and their life history patterns, and would require a study to determine the best location based upon species presence/absence, and the feasibility of moving the intake.

The option to relocate an intake may not be available to all facilities because of the potentially prohibitive construction costs. The authors are not aware of any California plants currently considering relocating an intake to depth or adding multiple pumps to allow for water intake at multiple depths although cost estimates for relocating the intake at Diablo have been conducted and they are thought to be excessive. However, it is worth mentioning here that SONGS has the deepest, and therefore longest, intake of any California OTC plant, and that they also have the highest impingement rates. Biologists and regulators seem to agree that the two are causally related, in that the long intake pipe is attractive to marine animals as a place of refuge, potentially for food, and possibly for other reasons not yet determined. This would seem to suggest that moving intakes farther away from the nearshore might have trade-offs in the form of decreasing entrainment but increasing impingement.

4.2. Variable Speed Pumps

Rather than relying on external factors such as fish behavior and screen maintenance, reducing intake flow directly minimizes the cause of entrainment (and impingement; Super 2005). This can be achieved two ways: by having multiple intakes that operate as needed to cool the plant, or by having variable-speed pumps on an intake to reduce water flow when the plant is not operating.

The principle behind reducing intake flow as an entrainment reduction measure is that the number of fish entrained is directly proportional to the volume of water removed. In other words, the more water used for cooling, the greater number of eggs and larvae entrained. Reducing intake water usage also offers the added advantage of increased intake screen effectiveness, because as screen slot width decreases, overall size of the screen must increase. Thus, lower water usage means a smaller area is needed for intakes and their screens and there can be a lower through-screen velocity. The issue of screen area versus flow velocity is addressed in Section 4.3.

An anticipated concern of variable speed pumps is that reducing cooling water flow will result in greater thermal stress to electric generation machinery. A study by ASA Analysis and Communications (Young 2005), found that a wide range of flows could still maintain thermal discharge and maximum change in temperature (delta T) within an acceptable range. The study was based on modeling from past generation load, water usage, and entrainment data at Roseton Generating Station on the Hudson River. By applying the constraints of keeping discharge temperatures below a maximum of 20°C to 40°C, and a delta T between 15°C to 30°C, water usage can be reduced by 63% to 70% over full withdrawal capacity. Using larval striped bass data, entrainment could be reduced by about 75% using this intake flow regime, compared with entrainment at full flow regime. These concerns still need to be addressed specifically with regard to OTC in coastal California applications, because different species reside in the area affected by the thermal plume, and delta T values approaching 30°C may not be permitted.

Plants that currently have one pump to draw water into the intake operate at the same water flow at all times and cannot adjust the volume of water they use. Thus, if and when the plant is not operating at maximum generation load, the facility is using more water than it needs. By installing multiple small pumps or one variable-speed pump, the plant can scale down water usage to match energy generation. This strategy could prove particularly useful for species whose maximum densities coincide with seasonal or diel reductions in generating load. For plants such as Roseton, where energy generation is highly variable, a load-based cooling water flow strategy alone could meet the 60%–90% reduction requirements under EPA's new phase regulations (Young 2005). Larval densities of striped bass around the intake at Roseton are highest at night, which coincides with periods of lower energy demand (Young 2005).

This technology is considered a relatively easy option in terms of the ability to retrofit the plant and requires little downtime for installation (Tim Havey, Tetratech, pers. comm.). However, it will only be a useful technology for those plants that have variable energy production demands. In addition, energy demand information needs to be paired with fisheries life history information to know how best to operate the pumps from an ecological view point. The details regarding spawning behavior and timing for many species in California that are affected by OTC remains unknown. As previously stated, there is a need for life history information of entrained species, so that maximum effectiveness in entrainment reduction can be achieved by reducing pumping during ecologically sensitive periods. Presently, one California OTC plant, Pittsburg, has a variable speed pump in place. Pittsburg is apparently not able to frequently use this technology for reducing entrainment, because of constantly high energy production demands (Tim Havey, Tetratech, pers. comm.).

4.3. Traveling Screens

The standard intake structure is equipped with conventional traveling screens with bars 3/8" apart. These were not originally developed to prevent entrainment of organisms, but as trash racks to prevent the entry of debris into the machinery. Therefore, they were designed to impinge items, including organisms. Impingement is limited to organisms that are too large to fit through the screen openings. For fishes, these are typically juveniles and adults as opposed to larvae. On a traditional screen without additional impingement reduction measures in place, impingement tends to increase as entrainment decreases. This is because as more organisms are kept out of the plant, more organisms are necessarily captured on the device put into place to keep them out. Understanding the tradeoffs between entrainment and impingement with different technologies under different scenarios is a research question that still needs to be addressed.

The standard screens have been modified in a number of ways to reduce entrainment and impingement. These modified screens are called traveling screens (see Figure 6).

4.3.1. Angled Screens and Induced Sweeping Flows

Setting traveling screens to an angle to incoming flow allows a component of the through-flow to assist fish in moving to the end of the screen line where there can be a fish return. The through-screen velocity is also referred to as the *approach velocity* and the across-screen flow is referred to as *crosscurrent* or *sweeping velocity.* It is possible to find an optimum ratio of sweeping to approach velocity to facilitate protection, even with the use of larger slot size (Dey 2005). In general, a high sweeping to approach velocity ratio improves biological effectiveness of screens (Dey 2005).

Figure 6. An example of a traveling screen (company name omitted to prevent bias; image obtained from freeshare website)

Coutant (2005) focused on the potential to reduce fish impingement. His central idea is to simulate a sweeping velocity, as is present with angled screens. This idea would potentially work just as well for reducing entrainment because small organisms tend to be transported by induced flows, instead of swimming around or against them. Pumps or baffles could sweep entrainable organisms toward a bypass or simply away from the intake. Dey (2005) provides a particularly interesting scenario whereby a pump set upstream of the cooling water intake could direct water, along with associated biota, back into the main body of source water (Figure 10 in Dey 2005). By diverting water outward and away from the intake canal, one is essentially creating a mock shoreline along which adult fish will continue swimming. Theoretically, this could work to direct eggs and larvae away from the intake as well, by keeping them in a different water mass with a safer outcome.

This scenario further exemplifies the need to understand fish behavior in relation to water intakes, as well as the response of early life stages to physical and hydrologic features of the site. How effectively these technologies can be applied under the sorts of oceanic and ecological conditions experienced at OTC facilities in California has yet to be determined.

4.3.2. Ristroph Screens and Fish Collection Systems

Cylindrical traveling screens may incorporate fish collection devices to minimize impingement. The technology is referred to as a *Ristroph screen.* The collection devices are often lifting buckets which hold the fishes in water until the screen rotates to the top and the impinged organisms are dumped into some sort of fish return, spillway, or bypass system that releases the fish back into the source water.

Although Ristroph screens have been developed to lower impingement, they are another example of a modified screen and are discussed here. To facilitate the removal of debris including impinged fish, traveling screens have also been modified into a cylindrical screen that rotates in the vertical plane, perpendicular to the through-slot flow. This has the advantage of rapidly dissipating flow in a manner that better allows impinged fishes to escape the immediate flow field. In addition, continuous rotation results in enhanced impingement survival; time spent stuck on the screen and accumulating physical damage is reduced. This strategy also reduces somewhat the need to use a high-pressure spray wash for removing gathered debris; a high-pressure wash can kill or re-impinge fish on a standard traveling screen.

Physical contact with the fish collection system may be the most problematic aspect of this technology. The species of fish mostly likely to become impinged on screens are midwater, pelagic, or open-water species. These species are not physiologically designed to deal with physical contact and, according to Duke Energy Morro Bay (2000), are least likely to survive such handling. Abrasion and stress resulting from handling also make fish more susceptible to disease or parasites. To be effective, such systems must be designed with biological sensitivity in mind. For example, making the collection devices out of soft or coated materials minimizes physical damage resulting from contact. The potential considerations associated with the fish return mechanism that takes fishes from the collecting device back to the open water are treated in Section 4.6.

Fish collection systems are not commonly employed and are often still considered experimental. Only three California OTC plants have modified traveling screens with fish collection devices in place (York and Foster 2005).

4.3.3. Fine Mesh Screens

Since the slats on a conventional traveling screen are too far apart to sufficiently reduce entrainment of small organisms, it is possible to equip the traditional trash rack, angled screen, or Ristroph screen with a fine mesh screen (usually with 5 mm openings or smaller). Some fine mesh screens may also be denoted as "wedgewire," referring to the triangular or wedge-shaped wires crossing over one another (Environmental Protection Agency 2001). It has been shown that a 1 mm mesh in such applications may reduce entrainment by at least 80% (Environmental Protection Agency 2001).

Generally speaking, one of the environmental concerns with deploying fine mesh screens is that reduction of entrainment impacts may result in concomitant increases in impingement. Impingement losses seem to be variable depending upon the time of day or year, and the species susceptibility to damage and temperatures experienced at the screens (Miller, in press). Some studies suggest that mortality resulting from impingement on a fine mesh screen may be low; less than 5% (Environmental Protection Agency 2001). However, others suggest that such mortality may exceed entrainment mortality (Taft and Cook 2005). These results are likely plant specific and depend upon the species being impinged, as well as the material the screen is made of and the application. Impingement survival is enhanced, for example, by presence of low through-screen velocity. Currently, the maximum through-screen velocity for fine mesh screens is set by the U.S. EPA at 0.5 feet per second (York and Foster 2005).

The general findings of recent pilot studies at other locations (mostly east coast and river systems) were that entrainment decreased with smaller slot size (i.e., 0.5 mm is more effective than 1.0 mm), lower through-screen velocity, and greater sweeping or crosscurrent velocity (Alden Research Laboratory 2003). Using fine mesh (0.5 mm or less), entrainment exclusion appeared high (in excess of 90%), while mean impingement rates remained low (Amaral 2005; Black 2007; Hanson 2007); less than 10% for all species tested in one application (Alden Research Laboratory 2003). Running the intake such that flow through the screens is stopped at regular intervals (i.e., 15 minutes "on"and 2 minutes "off") seem to allow organisms trapped against some screen types to drop off the screen and swim away in good condition (Hanson 2007).

There are two additional studies that were conducted by Alden Research Laboratory and funded by EPRI. The first of the studies was designed to field test cylindrical wedgewire screens using paired intakes; one screened and one unscreened to determine effectiveness. Testing was done at an estuarine site in Narragansett Bay, Rhode Island, and at a freshwater site in Lake Erie, Ohio. The results suggested reductions in entrainment that differed based on the species and through-screen velocity, although slot size did not have an effect (Alden Research Laboratory 2005). The second study was also a field study conducted near Gwynns Island, Virginia, in Chesapeake Bay. The results from this location revealed reductions in entrainment depending upon the species and through-screen velocity, as well as slot size (Alden Research Laboratory 2006). These types of screens have not been tested with California species, or in California's coastal and estuarine conditions. Therefore, as with other screening technologies, fine mesh wedge-wire screens are appealing, but still need to be tested.

It must be noted that using fine mesh screens with restricted through-screen velocities will also require increasing the surface area of the screens to ensure that enough water ultimately makes its way into the plant for cooling purposes. As slot width and/or through-screen velocity decrease, the surface area of the screen must increase to maintain the flow of water into the plant. Thus, this would require that the existing intake systems be reengineered to accommodate larger screens, and possibly more intakes to compensate for the smaller screen openings and low entrance velocities. Implementation of fine mesh screens depends ultimately on the feasibility of additions and modifications to the intake system and the available space for the additional intakes. Adding intakes may come at an additional cost, in the form of impacts to marine life, during the construction phase. Implementation will also require knowledge of site-specific biological criteria because the size distribution of eggs and larvae present (and needing protection) will vary with location.

A combination of slot widths small enough to exclude organisms in need of protection, low through-slot velocity, and high sweeping velocity will theoretically provide optimal screen performance (Dey 2005). Current regulations suggest that these need to be ~0.5 mm diameter or smaller, and through-slot flow needs to be 0.5 feet per second (fps) or less. Because mesh size and through-slot velocity must be small/low, the only parameter that can really be varied is sweeping velocity. The consequence of the very low values for the first two parameters is that sweeping velocity must be very high wherever these are deployed, and this may also limit where fine mesh wedge-wire screens (or any screens) can be deployed effectively.

There is also the potential for biofouling, although studies at other locations suggest this is small (Amaral 2005). But, this has been tested only in a limited application and appears to require the ability to backwash the screens at regular intervals (Black 2007).

There are currently no existing applications of fine mesh screens in coastal California, presumably due to space limitations associated with the large screens that would be required to maintain cooling water flows (Tim Havey, Tetratech, pers. comm.). Their applicability in general depends upon existing crosscurrent flows that serve to transport organisms away from the screen, just as in the case of angled screens. It is critical with this and other screening technologies to maintain a low and uniform through screen velocity. The reduction of flow in localized areas, whether due to collection of debris or an impinged organism, will result in accelerated flow through adjacent areas, making such regions more prone to injuring fish. Thus, it is unknown how well such screens will perform given the oceanic conditions present at many California OTC plants. A local field demonstration study would be required to infer screen effectiveness under coastal California conditions. This represents an area of need that could be addressed by the research program.

4.4. Barrier Nets

Barrier nets are simple nets extended around an intake zone to prevent entry by organisms. They are weighted at the bottom and have floats at the top to ensure they stay stretched and open. Barrier nets are easy to deploy, making them practical for seasonal implementation, and they are inexpensive compared with most technologies. With modern materials, they are also resistant to biofouling. These nets are in place at four plants in the United States (outside of California) and exceed performance standards for preventing impingement (Tim Havey, Tetratech, pers. comm.). These are useful only for preventing impingement, however, as larvae can still pass through the openings. In addition, a small amount of larvae grow to larger sizes within the enclosure and are subsequently impinged. Finer systems called *aquatic filter barriers* are required to prevent entrainment.

An aquatic filter barrier (AFB) is a semi-permeable mat of polyethylene or polypropylene fibers (Environmental Protection Agency 2001). One patented by Gunderboom Inc. is marketed as a Marine Life Exclusion System (MLES) and forms a full-water-depth curtain, floated on top and anchored at the bottom, in front of the water intake (Figure 7).[2] The MLES is designed with openings small enough to block nearly all eggs and larvae, and the material is soft enough such that impingement of otherwise entrainable organisms does not cause significant mortality. The main concerns with this technology are the potentials for clogging and biofouling. In addition, the 20-micron openings translate into a large screen area requirement, so this system may not be feasible in water bodies where navigation around the intake is a concern.

Figure 7. Deployment of the MLES at Lovett

Image from Gunderboom Inc.

An excellent discussion of the trials, problems, and solutions associated with the full-scale deployment of a MLES are in Raffenberg (2005). At Lovett Steam Electric Generating Station on the Hudson River, there was known to be a high degree of suspended solids, floating debris, and potential biofouling organisms (Raffenberg 2005). In this application, an automated airburst cleaning system was sufficient to remove sediment clogging and allow the fabric curtain to operate unattended over the duration of the study. Surprisingly, biofouling did not seem to adversely affect filtration of water through the fabric and exclusion of ichthyoplankton was over 80% effective, even though water spilled over the surface of the curtain throughout most of the evaluation (Raffenberg 2005). Furthermore, laboratory studies showed that egg viability and larval survival following impingement on the fabric were the same as for animals not exposed to MLES (Raffenberg 2005).

Nevertheless, longer-term biofouling remains a significant concern as it could reduce permeability of the curtain and damage the fabric. Potential biofouling organisms include algae, bacteria, funguses, mussels, and other sessile animals. Once established, a fouling community is very difficult to remove by mechanical means alone (Seaby 2005). Chemical biocides such as chlorine may be useful in some situations, but there is the concern that such measures may harm other organisms that the MLES is intended to protect. The primary problem with areas of

[2] See www.gunderboom.com.

reduced permeability due to biofouling is the subsequent development of regions where through-fabric flow would be increased, and to which delicate animals may become impinged. Another consequence of biofouling is that pathogens or parasites could become concentrated, or that a predatory community of filter feeders could become established on the fabric itself. It is also possible that motile predators such as crabs and larger fish could congregate along the face of the curtain, waiting to pick off the suspended plankton if there is insufficient water movement to carry impinged organisms away from the boom. Before this technology can be applied to California OTC plants, the potential effects of marine organisms biofouling the net over the long term, winds, tides, strong waves, and other oceanic factors must be considered. Further, it must be determined when and for how long this technology should be employed to minimize entrainment losses while minimizing equipment damage caused by long-term deployment.

4.5. Behavioral Barriers

Behavioral barriers work either by repelling fish from the intake, or attracting them to a bypass. Such barriers include velocity caps, light guidance systems, acoustic deterrents, air bubble curtains, and electrical barriers. Generally speaking, eggs and early-stage larvae lack the sensory and locomotor sophistication to detect the barriers and/or escape the intake. Therefore, most (but not all) behavioral barriers will be less useful for preventing entrainment, and the focus in this section is primarily impingement reduction (but see the discussion of velocity caps in particular).

A *velocity cap* is a device placed over the inlet that converts vertical flow to horizontal flow. This works on the principal that fish avoid rapid changes in horizontal flow and are relatively insensitive to vertical velocities. Six California OTC plants with oceanic intakes have velocity caps in place, although these do not eliminate impingement completely. Tests, however, are conclusive that they do reduce entrainment significantly. From both early studies and more recent, well-controlled studies, it is clear that entrainment may be reduced by as much as 90% when the caps are in place and conditions are such that visibility is high (Thomas et al. 1980 as revewied by Beck 2007).

Light guidance systems have been tested in a few applications, but they seem to have less success than acoustic systems. While it is possible to use lights to attract fish toward a fish return, most of the lighting devices tested have been used to repel fish from intakes. Light systems work best when there is a maximum contrast with the background, such as would occur at night or in deep water. As impingement of fishes has been noted to be greater at night, it may be that the ability to avoid an intake structure has a strong visual component. Strobe lights elicit an avoidance response and are more effective than mercury lights used for the same purpose (Weigmann et al. 2003). However, responses by fish are highly species-specific, and light systems can even be attractors in some cases. Therefore, these technologies may work best with a particular target species in mind and therefore need to be tested in California conditions with California species.

Acoustic fish deterrents are currently widespread in the United Kingdom among estuarine sites that use water for cooling (Henderson and Seaby 2000). In theory these eliminate physical contact of fishes with screens to minimize risk of blockage of cooling water systems and to minimize risk of injury to organisms. Possible advantages of this technology are that sound stimuli work even in a variety of conditions (even high water turbidity) and are low cost. The difficulty has been in finding a sound that is effective for a wide array of species and to which fish do not readily habituate. It has been noted that fish have optimum sensitivity to sounds and vibrations below 1 kilohertz (kHz) (infrasound and the lower range of human hearing) (Nedwell et al. 2005). Infrasound has been found to be most amenable to salmonids, which probably detect the vibrations in the water as a predator or obstacle to be avoided (Ploskey et al. 2000). High frequency sounds have been most successful at repelling clupeid fishes (genus *Alosa*) such as alewife and herring (Dunning et al. 1992; Nestler 1992). However, there is unlikely to be any effect of sound deterrents on eggs and early-stage larvae. Even if larvae have the sensory development advanced enough to detect sounds, it is unlikely that they are strong enough to swim against the incurrent flow to avoid entrapment, even at such a low recommended flow as 0.5 fps.

Less effective or applicable measures that have been tested include bubble curtains and electrical barriers. Air bubble curtains are largely ineffective for blocking or diverting fish because fish simply do not respond to them in any consistent manner. For a behavioral guidance system to work, it must give the fish a directional cue that leads it away from the source of danger (Nedwell et al. 2005). Electrical barriers, although they have been used with moderate success in freshwater systems, pose too much of a hazard in the high-conductivity medium of salt water to be used in marine or estuarine sites.

4.6. Fish Returns

Fish return mechanisms can be incorporated with a variety of technologies and provide a mechanism for getting fish that survive initial entrainment or impingement back out into the open water. Fish return mechanisms, whether by gravity or pumps, should attempt to minimize rough handling of fish that could increase their subsequent disorientation. The construction material should not abrade the fish, and various environmental parameters such as the amount of water (in the case of sluices) and quality of the water (i.e., temperature, dissolved oxygen, toxins) need to be maintained within the return.

Two California OTC plants have fish return systems in place and these are considered experimental. San Onofre Nuclear Generating Station (SONGS) has perhaps the most unique fish return system that incorporates a behavioral deterrent. At SONGS, the heat treatment applied to incoming cooling water is gradually applied, such that fishes in the intake experience increasingly warmer waters rather than instantaneous lethally hot waters. This stimulus, also called a *heat chaser,* works to guide fish back away from the heat and out the fish return. This works only for juvenile and adult fish that are capable of directed locomotion within the intake, however. Up to 75%, or more, of fish potentially impinged are returned alive through the

SONGS fish return (Love et al. 1989; P. Raimondi, pers. comm.). Nothing is known regarding the percentage of fishes returned in other systems.

Little attention has been paid to the long-term survival of returned fish. It has been observed, for example, that predators will often wait at the outlet of a fish return, having associated it with the regular release of dazed fish that make for an easy meal. Providing fish some mechanism to acclimate and reorient to their surroundings in a protected fashion could reduce immediate losses to predation. Longer-term studies that examine the fitness of returned fish are completely lacking and might be worthwhile for determining if the returned fish survive and contribute reproductively to the population. Similarly, the initial health of fish that are impinged needs to be established. Studies in fresh water systems, for example, have shown that fishes that are impinged tend to have significantly higher parasite and bacterial loads than fishes in the surrounding water body (Knight 2007). These results may suggest that fishes that become impinged are already physically compromised in some way and would not have otherwise impinged themselves. This result could have profound implications for estimating the impact of impingement losses on the community.

4.7. Concluding Remarks about Technology

Many fish protection technologies exist, and each has an effectiveness and practicality that can be site- and species-specific. Thus, there is probably no one technology that will meet the needs of every power plant. For any given facility, there may be several options available to them, some of which can be implemented simultaneously. Unfortunately, for some facilities, there also may be no options available to them from the currently recommended best technology available (BTAs; see Table 2), and mitigation might be the only feasible alternative.

Of the entrainment reduction technologies listed, all require full-scale field evaluation in California. With screening technologies, the potential for biofouling avoidance and treatment needs to be fully addressed in all cases. Also, the fact that some power plants will require very large screens to maintain cooling water flow rates must be taken into consideration from the standpoint of the intake's footprint. The possibility of using a combination of technologies, such as physical with behavioral, may be a worthwhile pursuit. Adding a behavioral component to a physical barrier, for example, may allow for larger mesh sizes, thereby reducing the footprint of the screened intake. One future research need is to evaluate entrainment reduction using one and two interacting technologies, specifically for the oceanic and ecological conditions associated with California OTC power plants.

5.0 Habitat Compensation and Restoration

When technology cannot be applied to reduce entrainment, mitigation strategies for the ecological losses caused by OTC have been used, and there are examples in California. Mitigation attempts to compensate for the losses when they cannot be prevented. In particular, two recent reports regarding effective mitigation of OTC/CWIS (Argonne National Laboratory 2003; Strange et al. 2004) affect mitigation.

Mitigation can be of three major types: (1) direct, on-site; (2) offsite, in-kind; and (3) out-of-kind. A fourth type, which is not really mitigation, is financial compensation for the value of the ecological losses. All four types require assigning a value to the losses so that it can be determined how much mitigation is required. That value may be assessed based upon HPF models that provide some estimate of the amount of habitat that would be needed to provide for the replacement of the same numbers of organisms lost to entrainment. The cost to obtain the acreage required to create such habitat may be the basis of this valuation.

Unfortunately, many knowledge gaps exist in regards to using habitat compensation as mitigation in California. The species and methods used to calculate the necessary habitat can result in differing amounts and types of compensation. The life history parameters of the species being affected will directly relate to which limiting habitat should receive compensation. Despite current practice, there is not a clear understanding of how best to assign a value to habitat loss and how to determine the true costs of any habitat compensation. Further, few mitigation efforts include follow-up monitoring to determine how effective the mitigation has been in offsetting the impact. In select cases, such as at SONGS, multiple studies and long-term monitoring have been in effect to track the results of restoration efforts. Without such monitoring, there is no way to determine if funds committed to mitigation efforts were sufficient or whether the habitat restored produced enough individuals to offset an impact. Even in the cases where there is monitoring, no one has developed any sort of metric for determining if a restoration effort is "successful." These issues all could be addressed through the research program with a focus on how to improve habitat compensation and how restoration is used to offset impacts.

6.0 Research Funded

The PIER program started its once-through cooling research program in 2005, released a request for proposals (RFP) in November 2006, and has funded seven projects to date (see Table 5). Some of those projects are a first step in answering some of the above knowledge gaps.

Table 5. PIER-funded studies

Principal Investigator	Affiliation	Title
Daniel Pondella	Occidental College	The Ichthyoplankton of King Harbor, Redondo Beach, California, 1974–2006
John Largier	University of California, Davis - Bodega	Improving Assessment of Entrainment Impacts Through Models of Coastal and Estuarine Withdrawal Zones
Joseph Cech	University of California, Davis	Bright Vibrating Screens: Increasing the Detectability of Fish Screens
Jonathan Geller	Moss Landing Marine Laboratories	Molecular Identification and Enumeration of Invertebrate Larvae Potentially Entrained by Once-Through Cooling in Morro Bay and Elkhorn Slough, California
Liz Strange	Stratus Consulting	Improve impact assessment and mitigation
Pete Raimondi	University of California, Santa Cruz	The Efficacy of Target Species in ETM Calculations
Charles Mitchell	MBC Applied Environmental Sci.	Life History Parameters of Common Nearshore Marine Fishes

The only other ongoing research program in the country that the authors know about is the EPRI program, which is funded largely through the efforts of utilities and the energy industry. EPRI has been publishing research results on once-through cooling since 1980 and have several targeted research programs in once-through technology and fish protection. The target is Clean Water Act 316 regulations, and includes thermal, impingement, and entrainment research. The program goal is to assess the effect of thermal power plant cooling system operation on fish and aquatic communities. Their research covers topics such as mitigation, analytical tools, and providing needed information and technical expertise to power plant operators that is useful for their compliance and regulatory needs. Highlights of the EPRI research can be found at www.epri.com and complete reports can be purchased through an annual subscription or on an individual report basis. EPRI does also provide newsletters, such as the *Technical News Quarterly*, which identifies recent research including those results that are published in peer-reviewed scientific journals. EPRI has funded several technology studies in conjunction with Alden Labs, including field studies, but these have not used California species or been applied under conditions analogous to coastal California. Much of the research is occurring in freshwater or in riverine systems on the East Coast or in the South. Most of the utilities that are members of EPRI are located outside the state, and EPRI conducts research in response to their members' needs. However, EPRI is conducting a few studies in California at present, including an assessment of the adverse impacts of cooling towers, and of fish protection technologies (Bailey 2007).

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8.0 Glossary

AEL	Adult Equivalent Loss
AFB	Aquatic Filter Barrier
BPJ	Best Professional Judgment
BTA	Best Technology Available
CalCOFI	California Cooperative Oceanic and Fisheries Investigations
CEQA	California Environmental Quality Act
CFD	Computational Fluid Dynamics
CSU	California State University
CWIS	Cooling Water Intake Structure
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
ETM	Empirical Transport Model
FH	Fecundity Hindcasting
fps	feet per second
GPO	Government Publications Office
HPF	Habitat Production Forgone
MGD	millions of gallons per day
MLML	Moss Landing Marine Laboratories
MLES	Marine Life Exclusion System
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
O&M	Operation and Maintenance
OTC	Once-through Cooling
PIC	Proposal for Information Collection
PIER	Public Interest Energy Research
PISCO	Partnership for Interdisciplinary Studies of Coastal Oceans

PM	Proportional Mortality
RFP	Request for Proposals
RWQCB	Regional Water Quality Control Board
SONGS	San Onofre Nuclear Generating Station
SWRCB	State Water Resources Control Board
USEPA	United States Environmental Protection Agency
WISER	Water Intake Structure Environmental Research

Appendix A

California Energy Commission - WISER Meeting Report

Appendix A: California Energy Commission - WISER Meeting Report

A public meeting was held on April 13, 2005 at the Moss Landing Marine Labs (MLML) in California to inform the once-through cooling program and address the knowledge gaps regarding the ecological impacts of once-through cooling by California's coastal power plants. The goal of the meeting was to produce a list of topics that could be discussed in more detail in a white paper and could be used to inform the research program. These topics relate to public interest energy research, as the funds used to make any grants come from the PIER program and need to meet the PIER program goals.

Dr. Lara Ferry-Graham, the MLML Program Manager, welcomed all of the participants to the meeting and introduced the program. The Water Intake Structure Environmental Research (WISER) program is located at MLML and funded by the California Energy Commission’s Public Interest Energy Research (PIER) program. It is through the WISER program that the RFPs will be announced and the grants awarded.

The PIER program has five different research areas. The contract with MLML is through the Environmental Area (PIER-EA). PIER-EA’s mission is to develop cost effective approaches to evaluating and resolving environmental effects of energy production, delivery, and use in California; and explore how electricity applications and products can solve environmental problems. Primarily, they aim to resolve impacts from electricity generation, transmission, and use. This might include addressing suspected impacts as well as doing basic research to understand implications. WISER is a program funded through PIER-EA that hopes to fill in some of the knowledge gaps regarding once-through cooling and its environmental impacts. The aim of the workshop was for the group to identify research needs. WISER cannot fund research that the power plant operators should do as part of their permitting process or their 316b phase II requirements. It is also important to remember that this is public interest research; it needs to address those areas of research that will provide the most benefit from these finite funds. Ideally this applied research will also inform the regulatory process.

Dr. Mike Foster provided an overview of the research that has been done to date, as far as is known to him, and pointed out some of the more problematic ecological issues..

1. Of all coastal power plants, 13 have not been assessed recently (since 1985; Encina is to be done soon). Two plants are on coast sand/rock, six on coast sand/harbor, and 13 in bay/estuary. A total of 17 billion gallons of seawater and used everyday.

2. There are 3 sorts of impacts: thermal, impingement, and entrainment. Traditionally, thermal effects (316(a)) have been of greatest concern. This is because populations of marine organisms were thought to be endless. Now we know thermal effects are usually minor, except maybe locally. Impingement (316(b)) of adult organisms on exclusion screens is also known to have relatively minor impacts. Entrainment (316(b)) of smaller organisms through the screens should probably be considered the most significant environmental impact.

3. The methods used to date to assess entrainment is usually to sample fish larvae at intake. Then, from life history and growth rate data, perform a Fecundity Hindcasting (FH) calculation, or an Adult Equivalent Loss (AEL) projection for key fish species. Studies on fish may focus on only 5 or 6 species. Other plankton and larvae affected are phytoplankton, zooplankton (including adult organisms such as copepods), and larvae of invertebrates such as crabs, clams and mollusks, and sea urchins. The number of organisms affected by entrainment, per 1000 m^3 of seawater, ranges from 2 to 200 species, and hundreds to billions of individuals per species. Of these, fish larvae are the most studied. There are, however, other larvae, like those of polychaete worms, which are never assessed.

4. From the data collected from sampling at intakes, we can perform AEL and FH calculations and compare these to fishery catches. Or, we can sample source waters and from there perform conversions based on Empirical Transport Models (ETM) to predict Proportional Mortality (PM) and Habitat Production Foregone (HPF). HPF is supposed to represent *all* species lost from the local environment. Using Morro Bay as an example, it was calculated that average PM was 17%. If we multiply that by 2000 acres of total habitat, we come up with 340 acres of habitat needed to produce larvae equivalent to those lost by entrainment. The applications of these models in inconsistent, and how to interpret the findings is less clear,

The meeting participants identified the following areas of research (which in part represent a synthesis of the ideas in Dr. Foster's presentation):

I. Develop long-term datasets for understanding coastal power plant ecological effects

A. Determine if these sets may already exist in some form for some areas

B. Determine the limitations of these existing sets

C. Design a study in one area of California as a pilot area

D. Monitor this area for a long term (possibly add other areas later)

Points to consider when developing a study:

1. What evidence would be needed to determine that there were power plant effects?
2. How would you monitor so that you could detect effects?
3. Where would you expect the effects to show up (near the plant or much farther away?)
4. What is the “signature“ of a power plant effect and how do you tease that apart from other anthropogenic and environmental effects?
5. What do these effects look like over the long term (cumulative effects over time)?

II. Which are the ”best“ metrics to use to measure an impact? What data is needed to determine which is ”best”?

A. Life history data, especially natural mortality coefficients and size-length or age-length relationships, are needed.

Points to consider when developing a study:

1. Are there existing datasets out there that are useful? Locate these?
2. Can ongoing studies (by other groups or agencies) be modified through collaborative effort so that they could provide the data needed?

B. These data translate to AEL, ETM, and FH, better data means better estimates

1. Is there a best model?
2. Can a single model be chosen, so that plants can be compared directly and cumulative effects determined easily?

III. Oceanography: What is the area of effect?

A. Hydrodynamic modeling is needed

B. Estimates of larval duration or retention times is needed

C. Are there existing monitoring stations that can be used to gather oceanographic information (IOS systems)?

IV. How can species that are entrained (or otherwise affected) be better identified/enumerated?

A. How can species of special status be identified/enumerated?

B. Are there techniques for species identification/enumeration that are cheaper, better, and faster?

C. Can "indicator" species be chosen, each of which biologically represents some portion of the other species being caught? All of the indicator species taken together should/could represent everything being entrained. Can these species be monitored as proxies for all the species, thereby improving understanding of power plant effects, but at a reduced cost?

V. Survey of California energy consumers (need economist)

A. Are they willing to pay X more on their bills to somehow offset entrainment losses?

B. Are they willing to do this without knowing the $ cost to themselves?

C. Are they willing to do this without knowing the "cost" of lost organisms?

D. How do you determine the cost or value of organisms (to the energy consumer)?

    1. What is the value of knowing the system is intact?
    2. What % loss is acceptable to the general consumer?

VI. What is the monetary benefit to California power plants of once-through cooling?

VII. What are the benefits (% reduction in entrainment) of technology?

A. Variable Speed Pumps or Variable Frequency Drives

    1. When would a plant ideally use the different speeds (if they can choose)?
        a. Requires a knowledge of what organisms are in the water, when (time of day and year) they are there, and what they are doing (i.e., spawning)
    2. Will flow reduction have a benefit?
        a. Can organisms actually escape intake if flow slower?
        b. Is there a trade-off of increased impingement with decreased entrainment?
        c. How important and/or detrimental is the increased thermal output that results?

B. Real field data needed for Gunderboom, Inc.

    1. Can you leave this on for extended periods of time?
    2. How much crossflow do you need to keep it clear of sediment?
    3. Biofouling

C. Fine mesh screen technology

    1. Can it really be implemented by the power plants (are field data needed)?
    2. What about fish behavior and attraction to the screens (Delta studies)?

D. Other viable reduction techniques?

    1. Sound barriers
    2. Bubble screens
    3. Fish returns (effective, but can we make these less costly)?
    4. Others?

VIII. Monitoring mitigation efforts

A. What are the criteria for success?

Points to consider when developing a study:

1. What variables do you measure?
2. Where do you measure (in and outside of affected area)?
3. Over what time frame?
4. What is "success"

B. Are there good indicator species that can be monitored to reduce the cost of overall monitoring effort?

Everyone at the meeting agreed that there were a few logical "next steps." First, they felt that getting the RFP out quickly would be important. Power plants are dealing with their 316(b) Phase II compliance now, and data produced in two or three years may not be useful—or worse, may reveal that they did not take the best measures that they could. Time is clearly of the essence. Second, the research goals are broad, and several focused RFPs may need to be addressed to produce the best results in getting the knowledge gaps addressed. Third, there are opportunities out there for collaboration on some of these monitoring and basic data collection studies. Finding someone who can identify the ongoing studies and determine how all of the resources can be combined for the most efficient mechanism of collecting data will be essential to getting as much from the PIER finds as possible.

Examples of these agencies are Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO), who are collecting basic larval fish life history information (and would need to be encouraged to add study sites relevant to coastal power plants), the Southern California Coastal Ocean Observing System (SCCOOS) that are putting buoys out to quantify ocean circulation and could provide data to determine the area of power plant effects (if they could be encouraged to put a buoy in a suitable location), and the power plant operators themselves that are monitoring via consulting firms (by adding money and collaborating the studies could be expanded to include population-level and cumulative effects). Each of these provides opportunities to get a large number of results with the addition of relatively little PIER money by pooling resources and taking advantage of programs that are active and already off the ground. Also, there are potentially existing datasets that could be mined if a person could be hired to identify them. Along the same lines, EPRI may have some data that could be made public and readily available through collaboration.

Appendix B

California Energy Commission - WISER Meeting Participants

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Appendix C

Results of Literature Review with Article Keywords indicated

Appendix C: Results of Literature Review with Article Keywords indicated

Search focused on: Entrainment, Fishes (primarily), Fish Swimming and Behavior especially around intakes or protection devices

AES Huntington Beach LLC (2004). AES Huntington Beach LLC generating station entrainment and impingement study. Huntington Beach, CA, AES Huntington Beach LLC, and California Energy Commission.

Keyword(s): entrainment; impingement; entrapment; fish return system; cooling water intake

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Keyword(s): 316(b); cooling water intake structures; fish protection technologies; intake screens; circulating water systems; NPDES permit

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